

NEUTRINO PHYSICS AND THE 25-FOOT BUBBLE CHAMBER

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The purpose of this note is to inquire into the feasibility of a class of neutrino experiments with the proposed 25-ft bubble chamber filled with hydrogen or deuterium. A great deal of the physics that can, in principle, be done with neutrinos has already been expertly discussed by S. Adler and M. Block in this Summer Study program, and I refer you to these papers for all relevant formulas.

For definiteness let us consider "elastic" neutrino events where the incident neutrino energy $E_\nu \lesssim 10$ GeV; i.e., events of type

$$\nu_\mu + n \rightarrow p + \mu^-, \quad (1)$$

$$\bar{\nu}_\mu + p \rightarrow n + \mu^+ \text{ and } n + p \rightarrow n + p, \quad (2)$$

$$\nu_\mu + n \rightarrow \Sigma^+ + \mu^-, \quad (3)$$

$$\bar{\nu}_\mu + p \rightarrow \Lambda^0 + \mu^+. \quad (4)$$

In the Brookhaven 25-ft bubble-chamber proposal,¹ there appear estimated event rates for a wide-band system with parameters as follows: for 5×10^{13} protons/pulse, $\sigma_\nu = 10^{-38} \text{ cm}^2$, visible chamber volume 72,000 liters, one obtains one ν event per picture in D_2 , 0.5 $\bar{\nu}$ event per picture in D_2 (half as much in H_2). Furthermore, the energy distribution of these events is 20% ($E_\nu < 5$ GeV), 40% (5-10 GeV),

40% (> 10 GeV). As M. Block has strongly suggested,² a special low-energy neutrino beam should probably be constructed to study low-energy neutrino events $E_\nu \lesssim 3-5$ GeV--such a narrow-band system has been suggested by Perkins in the 300 GeV Study Report Vol. II.³

With the wide-band system described above let us consider event rates in the 5-10 GeV region. A minimal interesting experiment for the E_ν and q^2 dependence of Eq. (1) I define to be one in which there are about 3000 elastic events in each 1-GeV bin from $E_\nu = 5$ to 10 GeV. We can then subdivide these 3000 events into 5 or 6 bins of q^2 , such that the last q^2 interval will have ~ 100 events ($\pm 10\%$). With such a sample, reasonable information about lepton current locality, CVC and axial-vector form factors should be obtained. Putting in more realistic parameters, such as protons per pulse hitting the neutrino beam target $= 2 \times 10^{13}$, and fiducial region equal to half the visible chamber, one needs 1.2×10^5 pictures for this experiment with neutrinos.

To go on from this stage to do the proton recoil polarization experiments with a similar statistical accuracy will require at least 20 times as many pictures with carbon plates in the chamber to scatter the recoil protons (which are strongly polarized, with momenta mostly less than 800 MeV/c). The importance of this experiment has again been stressed by M. Block. It will provide a much more sensitive test of CVC and also test for time-reversal non-invariance from second class current contributions. It would require $\sim 2.5 \times 10^6$ pictures in

the 25-ft chamber filled with D_2 .

The comparable elastic experiment with $\bar{\nu}$ on H_2 , where one looks for $\bar{\nu} + p \rightarrow n + \mu^+$ followed by $n + p \rightarrow n + p$, in order to identify the event as elastic, will also require $\approx 2.5 \times 10^6$ pictures even without polarization considerations. I have assumed a reasonably conservative 10% efficiency for the (n-p) elastic scattering process and included the factor of 1/2 for the lower $\bar{\nu}$ flux; assuming again 2×10^{13} protons and half the visible volume as the fiducial region. Such a run will again yield about 3000 elastic events per 1-BeV neutrino energy interval, but the polarization information on the recoil neutrino will not be as good as the previous case because of the much lower polarization analyzing power of $n + p \rightarrow n + p$.

It is important to note that the "elastic" scattering events at small q^2 can also serve to calibrate absolutely the intensity of the ν and $\bar{\nu}$ beams reaching the bubble chamber. The question arises as to how well one can distinguish the essentially 3c "elastic" events from inelastic events. A simple-minded look at the error-analysis problem (without FAKE, fitting, etc.) suggests that one is in good shape on this score for $E_\nu \lesssim 16$ GeV/c in the 25-ft chamber with 40-kG field. For example, assuming a setting error $\epsilon = 500\mu$, one has $(\Delta p)_\mu \leq 0.1$ GeV/c for $p_\mu \leq 16.5$ GeV/c (with a track length $l_\mu = 3$ m). In this momentum range $(p\Delta\theta) \ll 0.1$ GeV/c; the precision on the low-energy recoil baryon is, of course, very high. Furthermore, the low mass excited baryon states are produced at low energy in the laboratory so that

mesons emitted from the baryon vertex will have a broad angular distribution with only a very small probability of emerging in the ν direction.

At high neutrino energies, π^0 mesons emitted at the lepton vertex in the forward direction may begin to cause problems (D. Cline and W. F. Fry have alerted me to this possibility), and some auxiliary γ -ray detectors in the forward direction, either inside or outside the chamber, will probably be needed.

I conclude that very interesting "elastic," $\Delta S = 0$, neutrino experiments ($E_\nu \lesssim 10$ -15 GeV) can be done in the 25-ft chamber filled in turn with H_2 and D_2 provided exposures of the order of a few million pictures each can be made. The fact that such long runs are still required in the 25-ft chamber argues against settling for the 12-ft chamber, with H_2 or D_2 , for neutrino experiments at NAL, since in that case the number of pictures would have to be increased by a factor of four for the same statistics in the low-energy region, $E_\nu \lesssim 5$ -10 GeV.

If one now turns to the $\Delta S = \pm \Delta Q$ elastic events, such as Eq. (3) and (4), one finds that few-million picture runs are again required for significant new contributions to physics. The $\Delta S = +\Delta Q$ reaction $\bar{\nu}_\mu + p \rightarrow \Lambda^0 + \mu^+$ will be reduced by a factor of about 30 relative to reaction (2), so that a 2.5×10^6 picture run under our canonical conditions will yield ~ 1000 visible Λ^0 events in each 1-BeV bin from 5 = 10 BeV/c. Lambda-polarization information is immediately

available for these events, so again time-reversal invariance tests can be made, and interesting coupling-constant and form-factor information should be derived. The corresponding few million picture ν on D_2 run will provide a wonderful place to search for $\Delta S = -\Delta Q$ transitions of the type (3) $\nu + n \rightarrow \Sigma + \mu^-$, with good sensitivity down to $(\Delta S = -\Delta Q)\text{rate}/(\Delta S = +\Delta Q)\text{rate} \sim 10^{-4}$. This is more than two orders of magnitude better than current experiments, which in addition are limited to low q^2 .

Needless to say, these same pictures would contain much more interesting physics in the low-energy region that can be precisely analyzed, and, no doubt even more important, they contain many high-energy neutrino interactions which provide the prime hunting ground for intermediate vector mesons and four lepton interaction studies. These latter two problems will require electron and muon detectors in tandem, but I shall not pursue this matter here.

In conclusion, there are many exciting and feasible neutrino experiments in the modest neutrino energy region, $< 10\text{-}15$ GeV, that require few million picture exposures in the 25-ft chamber both with ν 's and $\bar{\nu}$'s and H_2 and D_2 . In addition, separate exposures to a narrow-band system for low-energy neutrinos will be desirable. Therefore, it is easy to see a productive program of "bread and butter" neutrino physics with the 25-ft chamber. Despite this chamber's size, it will still take many years to carry out this program.

I conclude with the recommendation that the construction of the 25-ft chamber for use at NAL be given a very high priority.

REFERENCES

- ¹ 25-Foot Cryogenic Bubble-Chamber Proposal, Brookhaven National Laboratory Report BNL-12400, Aug. 1968.
- ² M. Block, NAL Summer Study Report B.1-68-42, 1968.
- ³ D. H. Perkins, CERN/ECFA 67/16, Vol. II, 1967, p. 1.